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A LUMINOSITY SPECTROMETER FOR THE ZEUS EXPERIMENT AT HERA

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ABSTRACT

The HERA luminosity upgrade is expected to generate two major problems in the current method of luminosity determination which is based on counting brehmsstrahlung photons: damage of the calorimeter monitor due to high primary synchrotron radiation and large multiple event (pile-up) corrections. The luminosity spectrometer presented in this talk, is a novel method that reduces the impact of these problems in the luminosity measurement and is expected to yield a total systematic uncertainty of 1.4%. The spectrometer counts brehmsstrahlung photon conversions in the beam pipe exit window using two small calorimeters (former ZEUS beam pipe calorimeters) symmetrically placed away from the synchrotron radiation plane. The photon conversion rate is measured by counting electron-positron (ep) coincidences in the calorimeters. The ep acceptance is measured using a third calorimeter (6 meter tagger) which tags the brehmsstrahlung electrons. The electron-positron pair is separated by a small dipole magnet.

1 Introduction

ZEUS is one of the two colliding beam detectors operating at the HERA electron-proton collider at DESY, Germany. In September 2000, HERA completed an eight year running period which provided measurements of deep inelastic scattering (DIS) physics cross sections over a kinematic regime that spans several orders of magnitude of the DIS parameters, Bjorken x and photon virtuality Q^2 [1]. For the determination of the cross section σ the accurate knowledge of the luminosity L is required since $\sigma = R/L$ where R is the corrected measured rate of a particular DIS process. In ZEUS experiment the most accurate luminosity measurement achieved is 1.1%.

Currently HERA is undergoing a luminosity upgrade and is scheduled to start the new physics run in August 2001. The goal is to increase the peak luminosity from $L \simeq 1.5 \times 10^{31} cm^{-2}s^{-1}$ before the upgrade, to $L \simeq 7.5 \times 10^{31} cm^{-2}s^{-1}$ after the upgrade. The required accuracy in the luminosity measurement after the upgrade is $1 - 2\%$. The current ZEUS luminosity monitoring system has to be modified in order to meet the required accuracy because of two new major problems after the HERA luminosity upgrade:

1. Significant increase in the synchrotron radiation (SR).
2. Increase in the number of overlayed events (pile-up) for the physics process ($ep \rightarrow ep\gamma$) used to measure luminosity, to $1.3 - 1.5$ per HERA bunch crossing.

The luminosity spectrometer presented in these proceedings is a new method of measuring luminosity at ZEUS which solves the problem of SR and pile-up, meeting the requirements in the luminosity accuracy imposed by the ZEUS physics goals.

2 The new ZEUS luminosity monitor

ZEUS has been succesfully measuring luminosity using the Bethe-Heitler (B-H) $ep \rightarrow ep\gamma$ brehmsstrahlung process which is known theoretically within 0.5%. The photon is radiated with a very small angle with respect to the e-p axis ($\leq 1 mrad$) and in the past, the rate of these photons was measured by a calorimeter positioned in the HERA tunnel 107 meters away from the interaction point. After the luminosity upgrade, $300 - 500\ W$ of SR is expected to hit the photon

calorimeter at peak luminosity. Consequently one has to either shield and upgrade the calorimeter or find some other method of measuring the luminosity. ZEUS decided to do both. The proposed and approved new luminosity system for ZEUS is shown in figure 1.

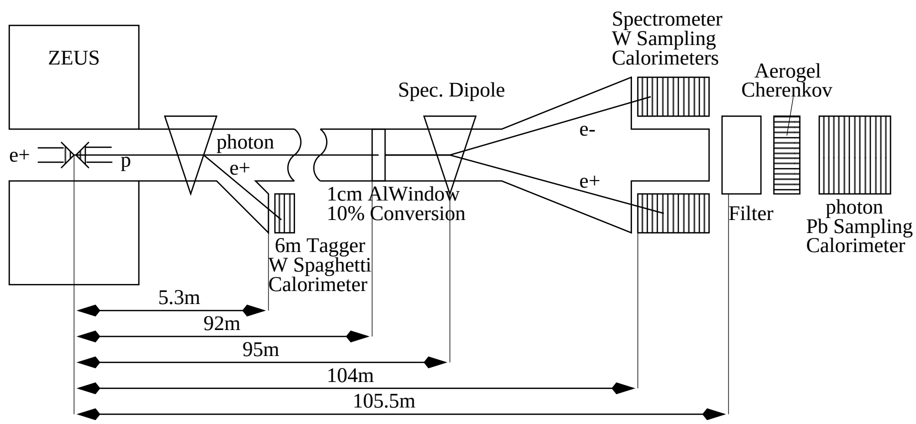

Figure 1: *A schematic of the upgraded luminosity system of ZEUS (side view). A B-H photon produced at the IP converts at the aluminum photon pipe exit window and the* e^+e^- *coincidence is recorded by two small W sampling calorimeters. The scattered B-H positron is detected by the "e tagger", a W scintillating fiber calorimeter positioned 5.3 m away from the IP. Non-converted photons are detected by the photon Pb sampling calorimeter.*

In this figure the photon rate is measured by two independent methods. First the upgraded old method; a combination of two filters and two aerogel cerenkov counters is placed in front of the photon calorimeter in order to block the SR and correct for the photon energy loss in the filter. The calorimeter energy resolution depends on the accuracy of the energy loss correction performed. The photon pile-up problem though is not solved and certain corrections have to be performed in order to reduce the systematic error due to pile-up. The second and new method of measuring luminosity is the luminosity spectrometer which solves both the SR and pile-up problems by placing two small existing Tungsten scintillator calorimeters away from the SR plane. The photon rate is

Table 1: *BPC characteristics.*

BPC specification	BPC performance
Depth	$24X_0$
Moliere radius	$13mm$
Energy resolution	$17\%/\sqrt{E}$ (stochastic term)
Energy scale calibration	$\pm0.5\%$
Energy uniformity	$\pm0.5\%$
Linearity	$\leq 1\%$
Position resolution	$< 1mm$
Time resolution	$< 1ns$

measured indirectly by counting e^+e^- coincidences of photons converted in the photon pipe exit window (about 10%). The spectrometer has small acceptance in coincidences $\simeq 3\%$ and no acceptance in low energy photons, so that the probability of a pile-up photon coincidence is small. The major contribution in the total systematic error of this method is due to the error in the knowledge of the acceptance.

3 The Luminosity Spectrometer

The luminosity spectrometer consists of two well understood small ($12cm \times 12cm \times 24X_0$) Tungsten scintillator calorimeters which provide the energy and position of the incident electron, and of a dipole magnet to separate the e^+e^- pair. The calorimeter (former ZEUS Beam Pipe Calorimeter BPC) characteristics are listed in table 1. The spectrometer acceptance A is given by the formula:

$$A = A_{geom} \cdot A_{conv} \cdot A_z \tag{1}$$

where A_{geom} is the acceptance of the photon beam exit window (it is of order 90%), A_{conv} is the conversion rate (for the specific exit window this is $A_{conv} \simeq 10\%$), and A_z describes the $z = E_e/E_\gamma$ dependent part of the acceptance. The spectrometer A_z part of the acceptance as a function of the converted photon energy is shown in figure 2. The e^+e^- coincidence acceptance is relatively uniform in the 18-23 GeV photon energy window. All of these accepted coincidences are coming from symmetric conversions i.e. they have $z = 0.5 \pm 0.2$.

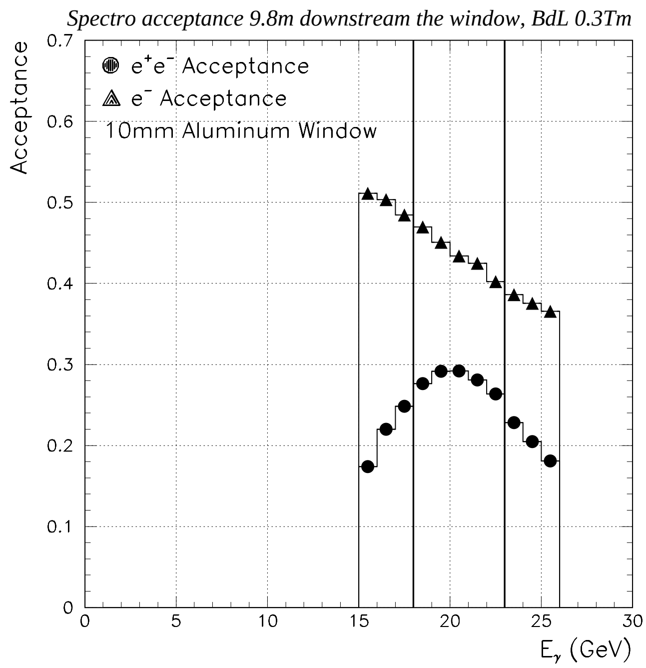

Figure 2: *Spectrometer acceptance as a function of the converted photon energy (conversion factor was omitted for simplicity).*

In the spectrometer method the acceptance is actually measured using a new small Tungsten scintillating fiber calorimeter, the 6-meter tagger (6mt) placed 5.3 meters away from the IP. The 6mt has 100% acceptance in brehmsstrahlung electrons in an energy window where the spectrometer acceptance is maximized (figure 3). A coincidence between the 6mt and the spectrometer should give a total energy equal to the electron beam energy: $E_e + E_\gamma = 27.5\ GeV$.

The expected coincidence rates are high thus providing an online statistically significant luminosity measurement. The converted B-H photon Gaussian profile on the exit window can be reconstructed within a few seconds. The e^+e^- origin Y coordinate Y_{hit} is approximated as the energy-weighted position of the two electrons as measured in the BPC's:

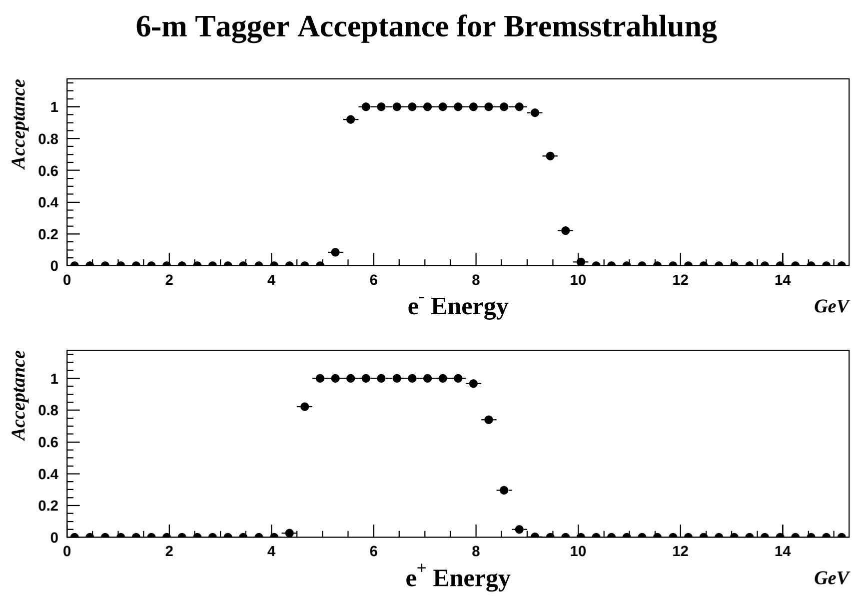

Figure 3: *Acceptance of the 6m tagger exit window for brehmsstrahlung electrons (top) and positrons (bottom). The acceptance is* $> 99\%$ *over the ranges* $6 - 9GeV$ *for* e^- *and* $5 - 8GeV$ *for* e^+.

$$Y_{hit} = \frac{E^+ \cdot BPC^+ + Y^- \cdot BPC^-}{E^+ + E^-} \tag{2}$$

where E^+, BPC^+ and E^-, BPC^- the energies and positions of the e^+ and e^- as obtained from the BPC's. The resolution obtained is around 5 mm with a 2 mm accuracy in the mean of a gaussian assumed profile. The photon profile will provide to HERA beam monitoring information.

A list of the most significant systematic errors of the spectrometer method is given in table 2 [2]. The counting, thermal γ background and proton-beam background errors are currently expected to be relatively low so they are not taken into account. The theoretical calculation of the cross section error was taken as 0.5%. The total systematic error is calculated by summing all errors in quadrature. The total systematic error is expected to be below 1.4%.

Table 2: *Systematic Error in luminosity measurement.*

Error Type	$L = 7 \cdot 10^{31} cm^{-2} s^{-1}$
Multiple event correction	$\leq 0.5\%$
egas bgnd subtraction	$\leq 0.5\%$
Total Acceptance error	$\leq 1.0\%$
Energy Scale errors	$\leq 0.5\%$
Cross-section Calculation	$\leq 0.5\%$
Total systematic error	$\leq 1.4\%$

4 Conclusions

The luminosity spectrometer method for measuring luminosity in the ZEUS experiment at HERA was presented. ZEUS is measuring luminosity by counting photons produced by the Bethe-Heitler $ep \rightarrow ep\gamma$ process. A 10% of these photons are converted in a thin exit window. The spectrometer measures the converted photon rate by counting e^+, e^- coincidences in two small well understood calorimeters. The calorimeters are away from the SR plane and pile-up is a secondary effect. The spectrometer acceptance is measured using an independent device, the 6m e-tagger. The tagger has almost 100% acceptance in B-H electrons in an energy window where the spectrometer acceptance is maximized. The electron and photon energy sum equals the electron beam energy (27.5 GeV). Detailed calculations show that the luminosity spectrometer can measure luminosity with an accuracy better than 1.4% [2)].

References

1. H. Abramowicz, A. Caldwell, Rev. Mod. Phys. **71**:1275-1410, (1999).
2. A. Caldwell, S. Paganis, R. Sacchi, F. Sciulli, *A Luminosity Spectrometer for ZEUS*, Internal ZEUS document, (1999).